STUDY ON REFORMED ETHANOL ENGINE

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ABSTRACT

The energy and the environment are the focus cared by the world. Ethanol as engine fuel for the transport facilities has some advantages, such as renewable, comparable power density. In this paper, a new approach –ethanol steam reforming, which uses common industry alcohol, is introduced for the existing engines. The main compositions of the gas from reformed ethanol include H_2, CO and unreformed ethanol, and with little CH_4, CO_2 and C_2*. The performances of the reformed ethanol engine, such as power, economy and emissions, have been studied in this paper. Compared to E100-engine and fuel cell, the reformed ethanol engine can be common spark ignition (SI) engine with few structure changes, and the hydrogen enrichment mixture needs no purification. The experimentation results indicate that it is feasible that the reformed ethanol is supplied to the engine. And the ignition performance of the engine can be improved by the mixture with hydrogen-rich. Moreover, lean combustion can be realized in the cylinder. The energy consumption performance and the emission performance are improved remarkably.

1. INTRODUCTION

Changing energy framework and reducing emissions from automobiles are necessary steps toward less dependence on fossil fuel, improving air quality and decreasing greenhouse gases. Transportation vehicles are the largest consumer of fossil oil and a major source of pollutants that affect urban areas. A variety of potential alternative fuels are currently being investigated: solar energy, wind energy, ocean energy, geothermal and biomass. To the technology of present status, ethanol is fit for the transport facilities in comparison with all other alternative fuels because of its relatively greater power density. For ethanol as engine fuel, there is a variety of types from E100 to E5 which are mature in the market, specially in Brazil and USA. But all need dehydrated ethanol and there are many structure modifications when ethanol is used to the existing engines in high rate. In this paper, a new approach –ethanol steam reforming, which uses common industry alcohol, is introduced for the existing engines with few structure changes. Moreover, the waste heat from exhaust can be used as energy source for ethanol steam evaporating and reforming. The ethanol steam reformate is a excellent fuel for engine because it is hydrogen-rich mixture. The properties of hydrogen will contribute to the combustion of the engine.

2. COMBUSTIVE PROPERTIES OF HYDROGEN

Table 1 compares selected combustion related properties of H_2 to those of gasoline.

TABLE 1: COMPARATIVE PROPERTIES OF GASOLINE , HYDROGEN

Property	Gasoline	H_2
Lean limit equivalence ratio in air	0.58	0.1
Flammability limits (volume %)	1.2-6	4-75
Laminar flame speed (m/s)	0.37-0.43	1.9-2.7
Spontaneous Ignition Temperature (℃)	280-400	574
Net energy density (MJ/m^3)	202	10.3
Quench distance (mm)	~2.0	0.64
Minimum ignition energy (MJ)	0.24	0.02

The properties of hydrogen that contribute to its use as a combustible gas areas follows:

2.1 Wide Range of Flammability

Hydrogen has a wide flammability range in comparison with all other fuels, which is fairly easy to get an engine to start. As a result, hydrogen can be combusted in an internal combustion engine over a wide range of fuel-air mixtures.

2.2 Low Ignition Energy

Hydrogen has very low ignition energy. The amount of energy needed to ignite hydrogen is about one order of magnitude less than that required for gasoline. This enables hydrogen engines to ignite lean mixtures and ensures prompt ignition.

2.3 High Autoignition Temperature

Hydrogen has a relatively high autoignition temperature. This has important implications when a hydrogen-air mixture is compressed. In fact, the autoignition temperature is an important factor in determining what compression ratio an engine can use, since the temperature rise during compression is related to the compression ratio. The temperature rise is shown by the equation:

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma - 1}$$

where:

V_1/V_2 = the compression ratio

T_1 = absolute initial temperature

T_2 = absolute final temperature

γ = ratio of specific heats

The temperature may not exceed hydrogen's autoignition temperature without causing premature ignition. Thus, the absolute final temperature limits the compression ratio. The high autoignition temperature of hydrogen allows larger compression ratios to be used in a hydrogen engine than in a hydrocarbon engine.

This higher compression ratio is important because it is related to the thermal efficiency of the system. The theoretical thermodynamic efficiency of engine is based on the compression ratio of the engine and the specific-heat ratio of the fuel as shown in the equation:

$$\eta_{th} = 1 - \frac{1}{\left(\frac{V_1}{V_2}\right)^{\gamma - 1}}$$

Where: η_{th} = theoretical thermodynamic efficiency

The higher the compression ratio, the higher the indicated thermodynamic efficiency of the engine. The compression ratio limit of an engine is based on the fuel's resistance to knock. A lean hydrogen mixture is less susceptible to knock than conventional gasoline and therefore can tolerate higher compression ratios.

2.4 High Flame Speed

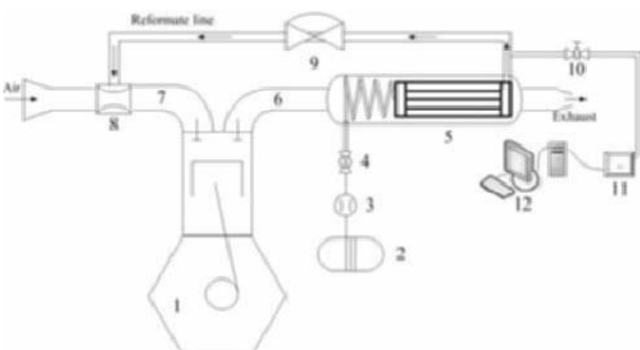
Hydrogen has high flame speed at stoichiometric ratios. Under these conditions, the hydrogen flame speed is nearly an order of magnitude higher (faster) than that of gasoline. This means that hydrogen engines can more closely approach the thermodynamically ideal engine cycle.

3. EXPERIMENTAL SET-UP

The reformed ethanol steam engine is based on spark ignition (SI) engine with a carburetor. The specifications of the SI engine are shown in Table 2.

TABLE 2: BASELINE SI ENGINE SPECIFICATIONS

Displacement	2.445
Number of Cylinders	4
Bore	92mm
Stroke	92mm
Compression Ratio	7.5
Max. Power	63kw
Max. Speed	3800r/min
Max. Operation Torq.	179



1. SI Engine; 2. Ethanol Tank; 3. Flowmeter; 4. Ball Valve; 5. Evaporator & Reactor; 6. Exhaust Outlet; 7.Air/Fuel Inlet; 8. Venturi Mixer; 9. Pressure Regulator; 10. Sample Valve; 11. Gas Chromatography; 12. Computer

Fig. 1: Schematic of the reformed ethanol engine system.

Figure 1 shows the schematic of the reformed ethanol engine, which consists of a baseline SI engine, and a set of ethanol supply system with an evaporator and a reactor. In addition, there is a gas chromatography for analyzing the compositions of the reformate from ethanol steam. The mixture of ethanol and water from the fuel tank flows to the evaporator where it becomes gaseous due to absorbing the heats from engine exhaust. Then the gaseous fuel is induced into the reactor which is filled enough catalysts. In the reactor, ethanol steam is reformed to hydrogen-rich gas mixture. The reformate flows through a pressure regulator into a Venturi mixer assembled on the intake manifold. The mass flow rate of the reformate is in proportion to the pressure difference between the throat of Venturi mixer and the pressure regulator where the pressure is maintained stably, which will be regulated automatically as the negative pressure varies in the Venturi throat due to the variation of the engine speed and its load.

The engine exhaust emission measurements were accomplished with an exhaust analyzing system from Horiba, Horiba MEXA-1500D Exhaust Analyzer. This system was used to measure oxygen(O_2), carbon dioxide(CO_2), carbon monoxide(CO), oxides of nitrogen(NOx) and total hydrocarbons(THC), via a heat pipe from the engine.

4. RESULTS AND DISCUSSION

The engine is still started by gasoline. When the temperature of the exhaust reaches about 300℃, the fuel is shifted from gasoline to ethanol. Then the liquid mixture of ethanol and water becomes gaseous ethanol steam after flowing through the evaporator, and the ethanol steam is reformed in the reactor. The reformate, which pressure is controlled by the pressure regulator , is mixed into the air in Venturi mixer.

5. REFORMING OF ETHANOL STEAM

The reformate gas from 75 percent alcohol is analyzed by GC-TCD. Figure 2 shows the recorded chromatogram of the compositions from ethanol steam reforming.

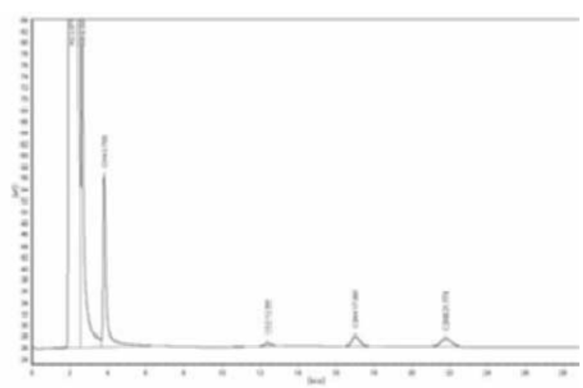


Fig. 2: The chromatogram of ethanol steam reformate gas.

The gas chromatography (GC) analysis indicates that the reforming yield is H_2, CO, CH_4 and CO_2 as the main products, and with little C_2*. Table 3 has shown the volume concentration of the compositions in the reformate gas.

TABLE 3: CONCENTRATION OF THE REFORMATE GAS COMPOSITION (V/V%)

Composition	H_2	CO	CH_4	CO_2	C_2H_4	C_2H_6
Concentration	58.4	23.3	6.5	1.6	1.7	1.4

6. PERFORMANCES OF THE ENGINE

The performances in different modes including gasoline, gasoline-ethanol, gasoline-reformate and reformate for the engine are researched at the same operating condition of 50 percent load and 2000rpm. Figure 3 show the comparison of NOx emissions and Lambda in different modes respectively. Here Lambda is the ratio of air to fuel in relationship to the stoichiometry of combustion, denoted by λ. While a λ of 1.0, there is exactly as much air as required to react completely with the fuel in an air-fuel mixture. While a λ greater than 1.0, there is an excess amount of air in the mixture which is termed ‘lean mixture’. While a λ less than 1.0, there is an excess amount of fuel in the mixture which is termed ‘rich mixture’.

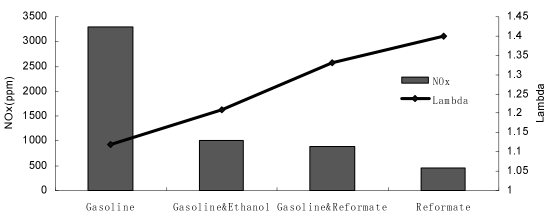


Fig. 3: NOx emissions and lambda in different modes.

Compared to base engine, the energy consumption with the reformate was reduced approximately 10 percent. Figure 4 shows the comparison of NOx emissions and corresponding Lambda. The NOx emissions with the reformate is about one order of magnitude less than those with gasoline.

Large improvement in energy consumption and reductions in emissions from the engine are possible by operation under lean conditions with the joining of hydrogen. In general, the max λ for gasoline is about 1.1. But the λ for the reformate with hydrogen-rich is up to 1.4. Hydrogen increases flame speed and extends the lean limit of the engine operation. The combination of enhanced flame speed and wider flammability limits of hydrogen can thus stabilize combustion during lean operation. Very lean fueling of engine could reduce NOx emissions by a factor of one hundred relative to NOx emissions at stoichiometric fueling.

7. CONCLUSION

The reformate from ethanol steam is hydrogen-rich gas mixture and is excellent fuel for engines. The energy consumption of the reformed ethanol engine was improved remarkably and the NOx emissions were reduced substantially. The farther researches for common industry alcohol as engine alternative fuel are significative works.

8. ACKNOWLEDGMENTS

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